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**Improvement of Product Development Cycle Time
and Cost by applying Concurrent Integrated
Design and Assembly Planning**

by

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Department of Engineering**

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I, Tat Lun Ng, hereby declare that this Eng.D portfolio, entitled "Improvement on product development cycle time and cost by applying Concurrent Integrated Design and Assembly Planning", which I am submitting, represents my own work and has not been previously submitted to this or any other institution in the application for admission to a degree, a diploma or any other qualifications.

Signed : _____
Tat Lun Ng

Dated: 15 December 1996

Abstract

Sonca is a manufacturing operation producing torches and lanterns. In order for the Company to be competitive, one of the key factors is to introduce new products to market quicker and at a lower total product cost. A system titled “concurrent integrated design and assembly planning (CIDAP)” is developed to aid this process.

It is identified that methods proposed by other researchers using different algorithms are not interactive enough and need too much space to store the representation of assembly sequences and time to process the assembly operations for a complex assembly. Besides, the commercially available systems and software are not integrated and are too universal. The data used is not compatible with the company’s data file.

The CIDAP framework focuses on concurrent and integration, in that the different processes in the whole product development cycle are carried out concurrently and are integrated. In the framework two techniques, namely KALG (Knowledge-based Assembly Liaison Graph) and KPN (Knowledge-based Petri Net) and four expert systems for selection of assembly system, feeder, gripper, and sensing technology are developed. Commercially available software such as Boothroyd and Dewhurst’s DFMA (Design For Manufacture and Assembly) software, Rapid Prototyping and Quick Tooling are also applied in the framework

The frame work and the systems are applied to an actual case in designing a series of torches within the Company. Results show that the product development cycle time is improved by 25%, rework cost reduced by 20%, and final product cost reduced by 11%. The Company has adopted the new framework.

The developed systems and data files are not only applicable to the Company, but also to other small and medium size companies in Hong Kong and China with a similar scale and nature of operation.

Executive Summary

Contents

| | | |
|----------|---|-----------|
| | Glossary | 3 |
| 1 | Introduction | 5 |
| 2 | Recent development on design and assembly planning | 9 |
| 3 | Literature review | 13 |
| 3.1 | assembly modelling | 13 |
| 3.2 | Assembly system | 15 |
| 3.3 | Petri Net based assembly and disassembly planning | 16 |
| 4 | Ideas developed in the Project | 17 |
| 4.1 | Concept of Concurrent Integrated Design and Assembly Planning | 17 |
| 4.2 | Product design for assembly | 19 |
| 4.3 | Assembly planning | 21 |
| 4.4 | Knowledge-based Assembly Liaison Graph (KALG) | 22 |
| 4.5 | Knowledge-based Petri net (KPN) | 23 |
| 4.6 | Flexible assembly system | 24 |
| 4.7 | Tool Kit, CIDAP Expert System (TKIT-CIDAPES) | 24 |
| 5 | Application of developed model to live cases | 25 |
| 5.1 | Design objective | 25 |
| 5.2 | Work involved | 26 |
| 5.3 | Results | 29 |
| 6 | Achievement/Innovation | 31 |
| 7 | Conclusion | 33 |
| 7.1 | Application of CIDAP within the Company | 33 |
| 7.2 | Application of CIDAP outside the Company | 35 |
| 7.3 | Future work | 36 |
| 8 | References | 37 |
| 9 | Bibliography | 39 |

Glossary

| | |
|----------------|---|
| ALG | Assembly Liaison Graph |
| AOPC | Assembly Operations Process Chart |
| AutoCad | It is a computer-aided design software tool developed by AUTODESK used to speed up repetitive drawing tasks and simplify drawing revisions. |
| BDI | Boothroyd and Dewhurst, Inc. |
| CAAPP | Computer Aided Assembly Process Planning |
| CAD | Computer Aided Design |
| CE | Concurrent Engineering |
| CIDAP | Concurrent Integrated Design and Assembly Planning |
| DFA | Design For Assembly |
| DFM | Design For Manufacture |
| DFMA | Design For Manufacture and Assembly |
| ES-ASS | Expert System for Assembly System Selection |
| ES-FS | Expert System for Feeder Selection |
| ES-GS | Expert System for Gripper Selection |
| ES-STTS | Expert System for Sensing Technology Selection |
| FAS | Flexible Assembly System |
| H230 | A two R14 cells torch with small size lens-ring |
| H300 | A two R20 cells torch with regular size lens-ring |
| H500 | A three R20 cells torch with regular size lens-ring |

| | |
|-----------------------|--|
| H550 | A three R20 cells torch with large size lens-ring |
| IDAP | “Integrated Design and Assembly Planning” by H. J. Bullinger and M. Richter |
| IGDS | Integrated Graduate Development Scheme of the University of Warwick |
| KALG | Knowledge-based Assembly Liaison Graph |
| KPN | Knowledge-based Petri Net |
| OEM | Original Equipment Manufacturer |
| PBS | Push button switch |
| PDS | Product Design Specification |
| Petri Net (PN) | A net-theoretic approach developed by Carl A. Petri in 1962 to model and analyse complex communication systems by capturing the precedence relations and structural interactions of stochastic, concurrent and asynchronous events. |
| Pro-Engineer | It is a software tool developed by Parametric Technology Corporation used to automate the mechanical development of a product from its conceptual design through its release into manufacturing. |
| QT | Quick Tooling |
| RP | Rapid Prototyping |
| The Company | Sonca Products Limited |
| TKIT-CIDAPES | Tool Kit, Concurrent Integrated Design and Assembly Planning Expert Systems |

1. Introduction

The Research Engineer works in Sonca Products Limited (the Company) as managing director. He joined the Company in 1965 as a mechanical engineer.

The Company is a multi product company set up in Hong Kong in 1953. In 1996, it had headquarters situated in Hong Kong and two factory plants, one in Pearl River Delta of China, and the other in Macau. The headquarters has a floor area of 3,600 square metres and employs around 180 employees. It houses all functional departments excluding the manufacturing operations. The plant in China has a production floor area of 35,000 square metres. The whole campus for the production facility, the dormitories, and amenities has a site area of around 60,000 square metres. The number of employees is around 2,200. The branch factory in Macau is much smaller in size. Its production floor is 5,000 square metres housing around 150 employee.

The company is the most vertically integrated operation in the field of torches and lantern manufacturing. It has its own industrial design, engineering design, manufacturing and process design, marketing and sales, inbound and outbound logistics, and of course, finance and human resources functions. The manufacturing also covers the full spectrum of operations including its own metal forming, plastic injection moulding, plastic blow moulding, surface finishing (including vacuum metallising, mechanical polishing, anodising, electro-plating

and electrostatic spraying), assembly and packing. Apart from having its own in-house industrial design of the products, the Company works with two outside design consultants, one in the USA, and the other in Australia.

Since the start of the Company, it has stuck to a policy of producing products designed in-house for the world market using the Company's own brand name "SONCA". As such, product development is one of the important functions of the Company. For the past forty odd years, the Company underwent evolutionary changes in its approach in product development. The first approach which took place from 1953 to 1963 was the vertically integrated approach, in which the design and development of the product from the beginning to the end was done by one man with the various functions integrated vertically. The functions included product conceptual design, detail engineering design of the product, the design of the production processes, design of the assembly operation sequences, and the design/fabrication of special machines for torch manufacture.

The second phase was the functional department approach. It adopted the principle of specialisation. The design department was split into three departments, namely, the industrial design department, the product engineering department, and the industrial engineering department. Co-ordination of these three departments was carried out by the development manager in charge of the three departments. This was satisfactory given that the scope of the Company at that time was still of medium size, and that information technology was not so advanced as compared to today. This period lasted to about 1985.

The third phase was the TQM approach. This took place from 1986 to the present day. Product design and development is no longer the sole responsibility of the industrial design and the product development department. It is co-ordinated by a committee. There are four interim monitoring teams to help co-ordinate the cross departmental functionalities. This has proved to be very successful.

In the existing system using the TQM approach, the average product development cycle time is eight months. Close analysis reveals that about two to three months time was spent on the rework of the product design and modifying tooling after the first pilot run. In the competitive world of today, such a long product development cycle time and high rework cost is definitely not desirable. The Research Engineer believes that while the approach is a good one in terms of human aspects where all resources are pulled together by better co-ordination among all concerned departments, any break through would be in the technical aspects. This was the initiative behind this Project.

It is the Company's strategy to reduce the product development cycle time and the rework and the development cost. The Company employs a development manager reporting to the Research Engineer. In February 1994, the development manager resigned from the Company of his own accord. The Research Engineer decided to leave the post vacant until a suitable candidate could be found, rather than to fill the post by someone marginally capable for the job. In the mean time, the Research Engineer took on the job on top of his being the managing director. It was not until November 1994 that the post was filled. In the ten month period,

the Research Engineer wanted to spend time to develop a new system to improve the whole product development cycle and cost.

The objective, as detailed in Section 1.2.3 of the portfolio, was to research into the latest development on design and planning for assembly, and to develop a new system suitable for the Company and the light industry in Hong Kong using the concurrent and integrated approach aiming to:

- Shorten the product development cycle time to less than six months,
- reduce the rework in design and tool modification, and
- reduce the total product development cost.

The title of the Project is "IMPROVEMENT OF PRODUCT DEVELOPMENT CYCLE TIME AND COST BY APPLYING CONCURRENT INTEGRATED DESIGN AND ASSEMBLY PLANNING (CIDAP)".

The Company intended to introduce to the market a family of four waterproof torches, which would consist of: one two R20 cells torch with regular size lens-ring (H300); one three R20 cells torch with regular size lens-ring (H500); one three R20 cells torch with large size lens-ring (H550); and one two R14 cells torch with small size lens-ring (H230). The plan was to introduce the first two models to the market first. Pending good response from the market, the other two models would be introduced. It was estimated that the family of torches would have a product life of at least five years, and the average annual sales would be around four million pieces. The lights within the family would have basically the

same engineering design but with different sizes. They would use a common push button switch which was a standard product manufactured in the Company.

As for the switch, the Company produced a family of eight types of push button switches, namely PBS-1 to PBS-8. They all have common parts except the contactor used to make contact with the torch bodies. The idea of the exercise was (i) to review the design of the switch for assembly cost improvement, and (ii) to determine the optimum assembly system for them, i.e., whether by bench manual assembly, dedicated assembly or flexible assembly. The annual quantity requirement would be ten million pieces including those for resale as OEM items.

2. Recent development on design and assembly planning

As discussed in Section 1.3 of the portfolio, the traditional product-process method as suggested by Nevis and Whitney ^[1] is sequential. It does not take into account the liaison of each design activity. Therefore the process is costly, tedious, and does not help in optimising the product design and production. To solve the problem, many researchers looked into the concurrent and integrated product design approach. It means that the product design and its manufacturing system are considered and carried out concurrently and integrated so as to obtain an economically viable product and production.

Research also revealed that assembly has traditionally been one of the highest areas of direct labour costs. In some cases, assembly accounts for 50% or more of manufacturing costs and is typically at 20-50%. Since assembly is an important field influencing product manufacturing costs, most research work concentrates on the design for manufacture and assembly. The common approaches used are concurrent engineering (CE), design for assembly (DFA)^[2], design for manufacture (DFM)^[3], integration of product design with assembly process planning, (IDAP)^[4], generation and choice of assembly plans, flexible assembly system modelling and simulation, etc.

The choice of the assembly sequence affects the efficiency of the assembly process. Traditionally, the product assembly sequence was planned by an experienced production engineer. However, the planning of assembly sequences is a trivial and error-prone task because there may exist a large number of potential assembly sequences in a complex assembly especially in a flexible one and in concurrent engineering environments.

Many research activities have focused on various aspects of assembly sequence planning such as assembly modelling, assembly sequence representation, assembly sequence generation algorithm, etc. However, these methods can only represent partial assembly precedence knowledge. Homen De Mello and Sanderson^[5] proposed an AND/OR graph representation of all the possible configurations of the assembly and generate the assembly sequences of a product

using disassembly or decomposition method based on the assumption that the disassembly sequence is the reverse of a feasible assembly sequence.

There are methods proposed by other researchers using different algorithms as detailed in Section 1.4 of the portfolio. These methods and algorithms are less interactive and need much more space to store the representation of assembly sequences and processing time to process the assembly operations for a complex assembly.

In reviewing the work done by many researchers, the Research Engineer identified the following deficiencies:

- The systems are not integrated

Most of the developed systems concentrate in a special area. For example, DFMA of BDI is for the review of the design of parts relating to manufacturability and assemblability; AND/OR graph is for the presentation of the assembly sequence. They lack a concurrent and integrated approach to the problem.

- The systems are too universal

The systems are designed for general use. While they are comprehensive to cover different designs of products, they become too broad for a specific field. In using these systems, the Company finds that it takes much time to find the right data to apply them to the Company's use. It would be better for the

Company to develop its own expert system based on its own experience to speed up the process in actual application.

- Data are not compatible

This is the corollary of the above point. To build up the Company's own data file and expert system would greatly help reduce the processing time in applying the system as the data are compatible.

- The systems may not be applicable to small and medium size companies

The concurrent integrated product design systems developed by previous researchers are mainly for large companies. Their success is dependent on a team-based working environment and on the aid of practical support tools. These companies have enough capital to develop their specific design tools and enough technologists and technicians to develop new techniques. They have powerful design teams to develop new products. For small and medium size companies, because of the lack of design teams, certain decisions can not be made until others have been made. This limits the operation of integrated product design in parallel. On the other hand, they, having fewer designers, do not have the difficulty of co-ordinating the activities among themselves. Small or medium size companies need to respond quickly to market changes to achieve commercial success. They seldom develop new processes and techniques, but rather acquire them to their operations. These may be the major differences between small and large companies. The concurrent integrated design and assembly planning (CIDAP) is aimed at developing a system for the Company as

well as for the small and medium size companies in Hong Kong's light industries. It will use a quantitative and axiomatic method. Some existing technologies and computer-aided tools are used in implementing the methodology.

To overcome the above drawbacks, the Research Engineer decided to develop a concurrent and integrated design and assembly planning approach suitable for the Company and the light manufacturing industry in Hong Kong.

3. Literature review

3.1 Assembly modelling

The Research Engineer studied the assembly process suggested by Rampersad^[6]. It showed that assembly by means of material flows is linked to the parts manufacturing, and that by means of information flow it is integrated with marketing, product planning, product development, process planning, and production control. To understand the interaction between the various assembly variables is very important in the analysis and design of assembly systems, as well as in the product development and process planning. In order to realise a controllable design process and a high design quality, an integral assembly model is presented. It attempts to improve the insight into the interaction between the assembly variables mentioned. The model

suggested by Rampersad is shown below and detailed in Section 2.1.1 of the portfolio.

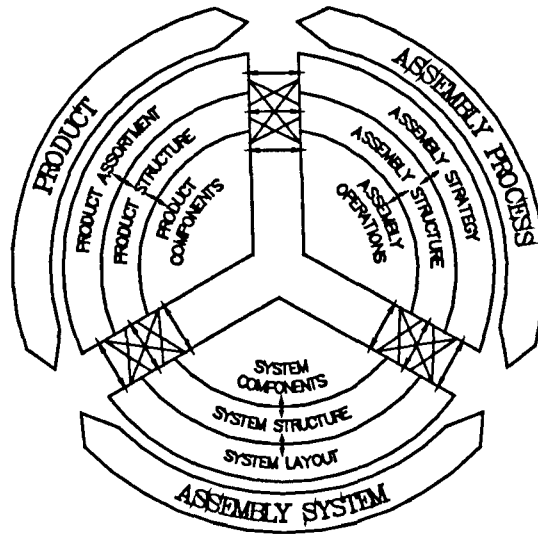


Fig. 1 An integral assembly model [Rampersad 94]

Rampersad discussed in detail the three relationships between (i) product assortment, assembly strategy and system layout; (ii) product structure, assembly structure and system structure; and (iii) product component, assembly operation and system components.

In assembly modelling, the most common method used to model mechanical parts is the geometric database of CAD systems. The liaison graph and its matrix representation show the relationship between two components. It can be implemented by the total relative constraints which can be extracted from the CAD drawing. The assembly liaison relationship of a product can be described by the assembly liaison graph (ALG)^[7] as highlighted in Section

2.1.4 of the portfolio. Based on this graphic presentation, a knowledge-based assembly liaison graph is developed.

There are three main approaches to the representation of assemblies such as language-based, graph-based and advance data structure representation. In this project, the AND/OR graph is used to represent the assembly sequence.

3.2 Assembly system

The two basic classes of assembly system are those performed by people (manual assembly) and those by mechanisms (automatic assembly). Manual assembly has two forms, namely bench and line manual assembly. Automatic assembly also divides conveniently into two categories, namely dedicated and flexible assembly.

For flexible assembly, the following areas were reviewed; design for robot assembly, specific assembly operation theories, axiomatic approaches, unstructured DFA rules and concepts, procedural methods, expert/knowledge-based systems, sensors, programming , languages, and off-line programming. In order to facilitate an easy reference to pick the right feeder, gripper, and sensing technology, this Project suggested three expert systems based on the experience gained within the company over the years.

3.3 Petri Net based assembly and disassembly planning

In recent years, with the rapid development of FAS (flexible assembly system), much research work has focused on the development of an intelligent robot flexible assembly planning system which is one of the important parts of FAS. In research done by Zhang in 1989^[8], Petri Net is applied to assembly. In his paper, Zhang presented an approach to model assembly and an algorithm to automatically derive the operation sequence by utilising Petri net model of assembly, while the goal and constraints are only specified. The representation of assembly in the form of Petri net produces an overall model of the goals which are to be achieved, the initial resource constraints and dynamic features of assembly. Based on the Petri net representation, the plan generation is quite straight forward and can be easily implemented with a simple matrix calculation. Details of Zhang's model are highlighted in Section 2.4 of the portfolio.

The model is a good approach to represent all the feasible assemblies, but lacks the ability to choose the best assembly sequence. In this Project, the Research Engineer, based on Zhang's approach, developed the knowledge-based Petri net. It supplements Zhang's model in that it introduces the flow control mechanism for choosing the optimum assembly sequence.

4. Ideas developed in the Project

4.1 Concept of Concurrent Integrated Design and Assembly Planning

There are many sophisticated procedures in product design and assembly system development. It needs many aspects of knowledge and experience, and requires team work. The sequential approach currently used in product design and assembly system development is not effective. It does not help in optimising the design of the product and assembly system. In order to obtain an economically viable design and assembly system for flexible assembly, product design and assembly process planning must be integrated and considered concurrently.

In Concurrent Integrated Design and Assembly Planning (CIDAP) as detailed in Chapter 3 of the portfolio, the product development process is divided into five stages. They are: *conceptual design, assemblability analysis & detail design, assembly system design, assembly planning and simulation, and economic justification*. They are carried out concurrently and are integrated. The analysis of manufacturability and assemblability, the detail engineering design of the parts, and the selection of assembly system and assembly sequencing will be iterated until the optimal design is achieved.

The whole procedure of the CIDAP is summarised in the following figure.

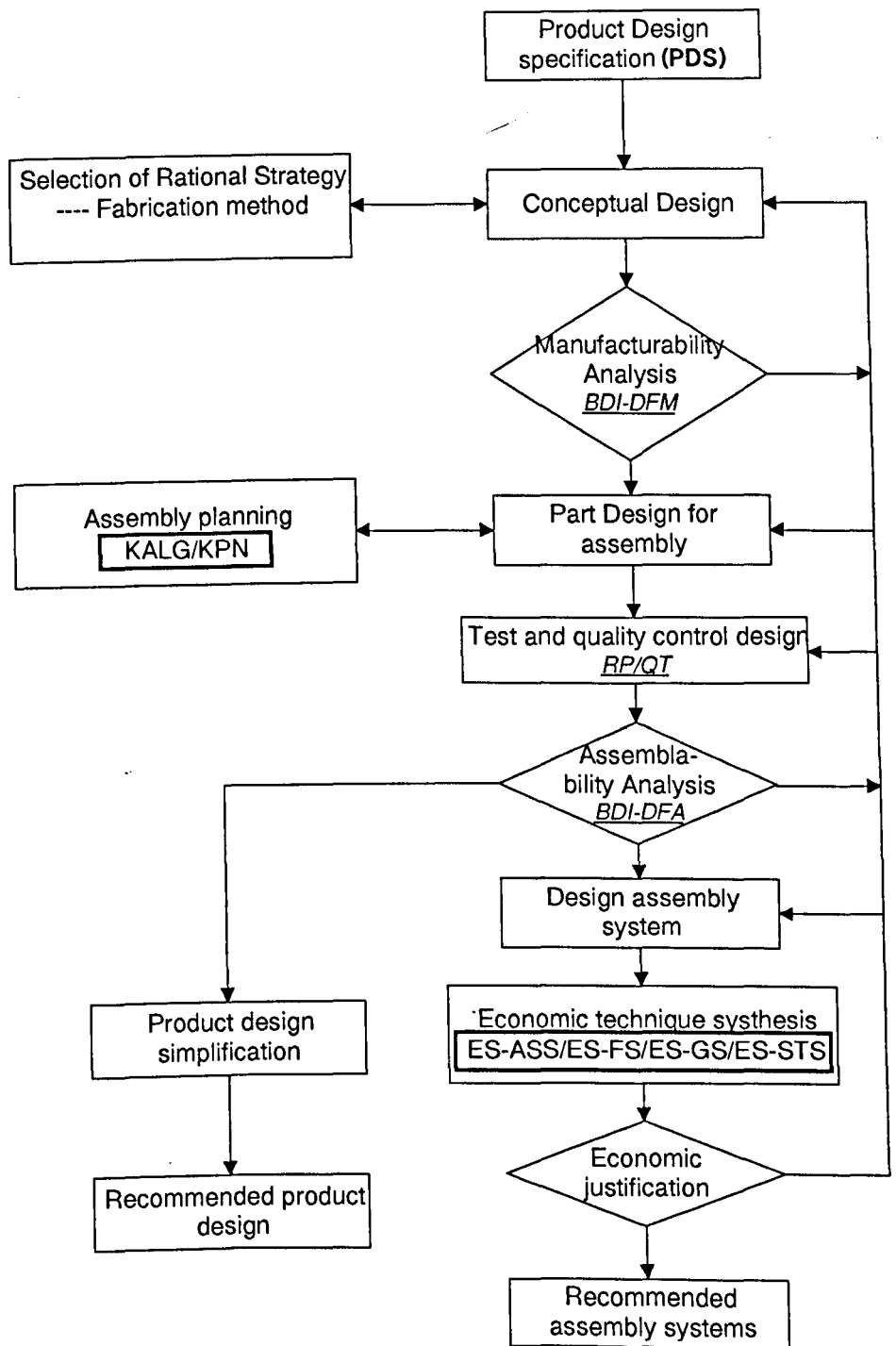


Fig. 2 Concurrent Integrated Design and Assembly Planning Flow chart

| | | |
|---------|---|------------------|
| BDI-DFM | means BDI's Design For Manufacture | |
| BDI-DFA | means BDI's Design For Assembly | |
| ES-ASS | means Expert System For Assembly System Selection | (Self-developed) |
| ES-FS | means Expert System For Feeder Selection | (Self-developed) |
| ES-GS | means Expert System For Gripper Selection | (Self-developed) |
| ES-STs | means Expert System For Sensor Technology Selection | (Self-developed) |
| KALG | means Knowledge-based Liaison Graph | (Self-developed) |
| KPN | means Knowledge-based Petri Net | (Self-developed) |
| RP | means Rapid Prototyping | |
| QT | means Quick Tooling | |

Before product design, the product specifications must be identified and documented. Section 4.1 of the portfolio discussed in detail the Product Design Specification (PDS), which is a document that contains all the requirements relating to the product outcome. It is the basic reference and the control for all design activities. It should be kept in mind that though PDS should be static at all times, it can however be subject to change if the specification of the product is out of reach of the most economical way of manufacture and assembly, or is not meeting the customers' requirement. When it comes for review, full investigation into the reasons why it needs to be changed should be carried out. In defining the PDS, non-manufacturing factors such as marketing, finance, material supply etc. should be considered as well. However these factors are beyond the scope of this Project.

4.2 Product design for assembly

In the design of a product, there are the following phases.

- **Conceptual design**

Conceptual design is referred to as a phase in design activities in which many alternative concepts are generated to comply with the requirements of the PDS. Conceptual design converts the PDS into a manufacturable and saleable product concept by clearly articulating all the associated goals, expectations, and constraints. Thus, it is also called constraint-based design.

- Constitution analysis of product

This involves the design of the parts and/or sub-assemblies to form the hierarchical structure of the product. Its goal is to find out the number of components, product structure, the common and non common components, and standard and non standard components.

- Consideration for manufacturability and assemblability

In this phase, designers should consider by which method the product should be fabricated and assembled. The Research Engineer adopted the BDI's (Boothroyd and Dewhurst) DFMA software ^[9].

- Selection of assembly systems

Product design including its part design depends highly on the assembly system to be used later. In this phase, BDI's software can be used to select the system of assembly. It contains a host of detail rules and strategies. In this project, an intelligent approach which employs simple cost estimating algorithms and expert system to perform the necessary ranking and decision making in terms of cost in concurrent product design is presented.

- Material selection and fabrication method

The choice of material can be referred to relevant manuals or handbooks. However, it is not an ideal method for the systematic selection of suitable process/material combinations for part manufacture.

- Detailed design

It includes calculation of design parameters, selection of material and fabrication method, determination of shapes, dimensions, and tolerances of product and its components etc. The Company uses AutoCad and Pro-Engineer. They are powerful tools and have interactive functions in editing graphics and drawings.

- The software

As mentioned earlier, part design for assembly has a close relationship with the assembly system to be used. Based on Lourdes^[10], this Project has initially implemented the integration between CAD and DFA analysis by two computer algorithms to calculate the overall dimensions and rotational symmetries of part data which are called DIMENSION and SYMMETRY respectively. The development of the above two algorithms, as detailed in Section 4.4.3 of the portfolio, is still at a very primitive stage in the Company. Unfortunately the technician who wrote the software left the Company to emigrate to Singapore, thus bringing the work to a temporary halt. Future work in this area will be carried on.

4.3 Assembly planning

Assembly planning refers to the generation and choice of assembly plans and the assembly operation process. The choice of the sequence in which

components or sub-assemblies are put together in the mechanical assembly of a product can drastically affect the efficiency of the assembly process. It was mentioned earlier that the product assembly sequence is traditionally planned by an experienced production engineer. It is time consuming and error-prone. There is a growing need to systematise and to computerise the generation of assembly sequences.

In this Project, focuses are put on the approach and the system for automatic generation of assembly sequences. They are key issues of computer aided assembly process planning (CAAPP). A new representation of product assembly relationship and assembly constraints and a methodology for generating the detailed feasible sub-assembly sets of assembly plans for a given product was presented using the technique of KALG (knowledge-based Assembly Liaison Graph).

4.4 Knowledge-based Assembly Liaison Graph (KALG)

In 3.1 above, it was mentioned that one of the powerful tools in the design of assembly sequence is the Assembly Liaison Graph (ALG). It is a graphical representation showing all the relationships of the different parts of the designed product. Again it lacks the ability to identify the unfeasible assemblies, resulting in a very large and complicated graph. This Project introduced the Knowledge-based Liaison Graph (KALG). The idea, as highlighted in Sections 5.1 and 5.2 of the portfolio, is to use the knowledge

gained within the Company to develop an expert system of basic rules and constraints to find out the unfeasible assemblies. By eliminating them, the feasible assemblies can be obtained. It reduces the time and effort in the assembly planning process.

To generate assembly or disassembly sequences automatically, an automatic knowledge inferring system is introduced to solve this problem. The programme is written in artificial intelligence language Turbo-prolog 2.0. All feasible sub-assemblies are generated by automatic inference and classification when the user answers questions about the assembly facts and information presented by the system. Alternatively the user can input the assembly knowledge-base file. The programme was still at a primitive stage. More work will be done in the future to debug and simplify it. Though the expert systems are developed for the Company, they may be useful to other industries of similar nature of production system and products.

4.5 Knowledge-based Petri net (KPN)

In the planning of a flexible assembly system Zhang^[8] suggested the Petri net approach. In Section 5.5 of the portfolio, a knowledge-based Petri net was developed as an extension of Zhang's basic Petri net model. The central idea is to introduce the flow control F_c , which describes the knowledge of selecting the sub-assembly sequence with the minimum sub-assembly time. An algorithm is introduced and its application to an actual case is presented.

4.6 Flexible assembly system

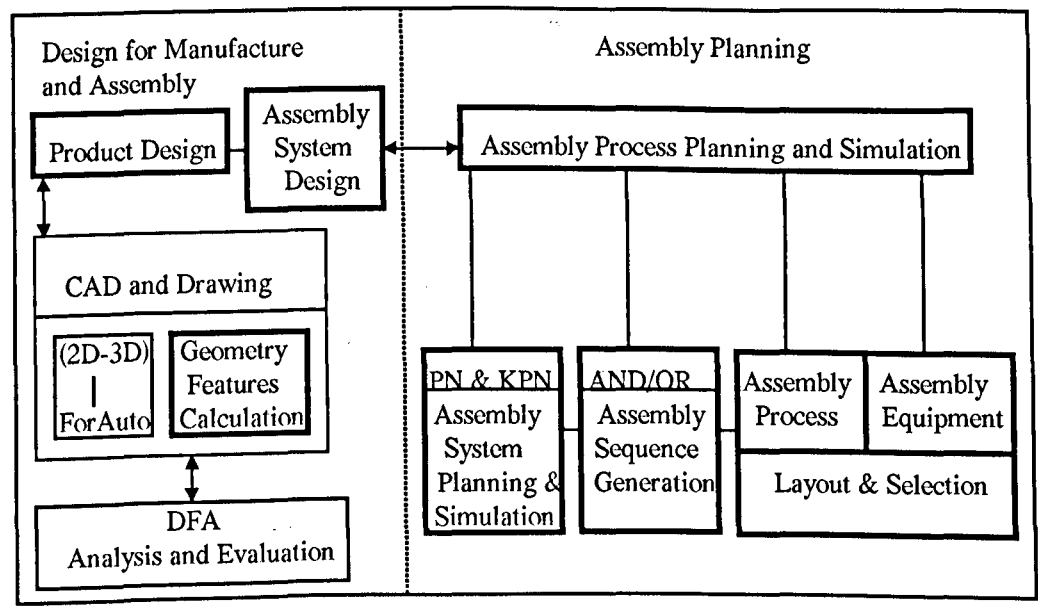
A critical step in the design of flexible assembly systems is the selection of feasible technologies in order to perform the required tasks cost-effectively. People are the most flexible assemblers and most dextrous, but their performance varies, and is difficult to be documented and held to a standard. A flexible assembly system is composed of some programmable robots and part handling devices. It offers an alternative combining the flexibility of people and the uniform performance of fixed automation. Therefore it meets the needs of various products in small to medium batch production.

In the area of design for flexible assembly, the Research Engineer developed the Assembly Operation Process Chart (AOPC) which is a part tree representation of the assembly sequence. In order to have a quick selection of the feeders, grippers and sensing technologies for the flexible assembly system, three expert systems were introduced. These systems were developed based on the experience within the Company. They are fully presented in Chapter 6 of the portfolio.

4.7 Tool Kit, CIDAP Expert System (TKIT-CIDAPES)

There is commercial available software in the market to aid the implementation of the computer-aided design and assembly planning. The Research Engineer finds them not too applicable for the Company's use

because of two reasons. The first is that they are mostly not integrated. The second is because they are designed for general use and may not be too efficient (in terms of quick reference) for the Company which produces one quite homogeneous product, such as a torch. As such, the Research Engineer developed a prototype expert system TKIT-CIDAPES (Tool Kit, CIDAP Expert System) as detailed in chapter 7 of the portfolio. A summary of the Tool Kit is shown below. Those expert systems and software in the bold line boxes were developed by the Research Engineer.



5. Application of developed model to live cases

5.1 Design objective

As mentioned in the outset, the Company intended to introduce to the market

a family of four waterproof torches, the H-series. They will use a common push button switch which was a standard product manufactured in the Company. As for the switch, the Company produced a family of eight types of push button switches, the PBS-series. They all have common parts except the contactor which is used to make contact with the torch bodies. The idea of the exercise was (i) to review the design of the switch for assembly cost improvement, and (ii) to determine the optimum assembly system for them.

The characteristics of a torch are variants and small to medium batch. The types of products are often changed according to the market requirements. The most important one for design and manufacturing is the appearance design. It must be appealing in aesthetics and ergonomics. From a marketing point of view, it is desirable to have a family of torches and to introduce them to the market together instead of introducing one single model at one time. This helps to promote sales and can aim for different segment of the market including men, women, and children.

5.2 Work involved

Details of the work involved is described in Chapter 8 of the portfolio. The following summarises the work done.

The Product Design Specification was first prepared, based on which, the conceptual design of the models was developed. Concurrently the developed

expert system and BDI were used to select the most economical assembly system. It was suggested that a special purpose free transfer system would be the preferred one. Thereafter followed the detail design and part design. In doing so the DFMA system of BDI was employed. A bill of material was then generated.

In assembly planning, the KALG technique together with the developed software was employed to find the feasible assembly sequences. This is applicable to both assembly by manual assembly and flexible assembly. The assembly processes for the torch and the switch were shown using the AND/OR representation, and the assembly sequences using the AOPC (Assembly Operation Process Chart). Finally, by applying the KPN (Knowledge-based Petri net) technique developed in the Project, the optimum assembly sequence was determined.

It was identified that a flexible assembly system is the most economical system for the assembly of the torch H-series and the switch PBS-series because of two reasons. The first reason is the family approach of both the torch and the switch in that each of the family of products are basically of the same construction with only slight variation in size. The switch PBS-series has eight versions, and the only difference is the contact strip which makes contact with the tube of the torch. The second reason is the economy of scale which is the corollary of the first reason.

The Company however decides to defer the adoption of the recommended flexible assembly system to a later date, and to adopt the manual assembly system with the recommended assembly operation sequence. The Company considered the investment of the project both in hardware and software in terms of human factors. As for the hardware, the Company was convinced that the investment would pay back in the long term. There would also be the fringe benefit of consistent quality, higher output, and shorter throughput time. The Company realises that labour costs will continually go up and if no automation or mechanisation is implemented, one day the Company will lose out to the competitors.

It was the software that made the Company hesitate to move ahead with the recommendation. The Company moved the manufacturing operation to Buji, China in 1987. In 1990, it expanded and relocated the operation to the present site in Bogang, China. All the technical staff including engineers, technician and craftsmen did not have over two years experience in the Company when the Project was started in 1993. By the time the recommendation was made in mid 1995, most of the technical people were not yet ready for flexible assembly using robots. In fact a large proportion of them had no working experience with robots. In running a robotics flexible assembly system, technical support in setting up, fine tuning and maintaining the robots are vital in making the project successful. In the absence of such support, the Research Engineer decided to defer the introduction. Instead, a manual assembly system was adopted. Two assembly lines were set up at the end of 1995 to assemble

the torches and the switches. The torch H300 and H500 were introduced to the market in late 1995. The Company will monitor the sales of these two models. By early 1997, it will decide whether to introduce the other two models. The introduction of them will add more weight to the scale of economy in assessing the use of flexible assembly system. By that time, i.e., mid 1997, the Company would also be in better position in having sufficient capable technical staff to set up, run, monitor and maintain the system.

5.3 Results

Detailed results are presented in Section 8.8 of the portfolio. The following is the summary.

Most of the parts of the new torch series were new except for some standard parts. As such they all underwent changes in the design process. The BDI's DFMA software helped identify deficiencies and recommend changes in the design of parts. Equally successful was the review of the existing switch. Based on the recommendation, the family of switches was redesigned and the unit production cost was lowered by 13%.

Previously the normal product development cycle from approving the appearance design to the launch of the product was around eight months. The use of CIDAP to the design of the new torch series proved that the product

development cycle time was reduced to only six months, that is a reduction of 25%.

During the whole process, CIDAP framework was applied and the team approach was practised. It resulted in a reduction of the total cycle time, mainly in the rework of the design and time saving in performing concurrent product design, tool design and tool making. The time saving for the former was about one and half months, while the latter contributed to the other half month time saving. It was observed that there would have been around 20% reduction in tool rework cost when gauged by the normal percentage of rework recorded in previous designs.

Other management time spent on the product was also less. Though it was not formally recorded, it was reported that the overall product development cost for the Project was less by 23%.

Before the product was approved to go ahead for development, the estimated unit cost was prepared. When the product was later introduced to the market, the unit cost was finalised. It was 89% of the estimated one. The saving was in the two areas of material cost and labour cost. It was brought about by the better design of the product based on the suggestions of redesign and by the more efficient assembly operation.

Apart from the tangible benefits mentioned above, the Research Engineer observed a higher morale in the organisation, because of less rework and shorter delivery time.

6. Achievement/Innovation

The CIDAP (Concurrent Integrated Design and Assembly Planning) framework is an integrated system. In the process of product development, the design of the product, the selection of the assembly system and assembly sequencing are carried out concurrently and are integrated. The framework has four advantage over those proposed by other researchers as follows:

- simple

The framework is designed purposely for the Company while the commercially available systems or software are designed for general application. As a result, the developed framework and techniques are simple.

- Easy to use

The data file used in the two techniques and systems are generated based on the data cumulated within the Company. Hence it can be used easily by the engineers within the Company.

- Compatible data for whole process

All the activities in the framework use the same data file.

- PC based

The developed systems use personal computers and do not require a mainframe which most small and medium size companies do not have.

In the framework, two techniques, namely KALG (Knowledge-based Assembly Liaison Graph), and KPN (Knowledge-based Petri Net), and four expert systems used for flexible assembly for the selection of the assembly system, feeder, gripper and sensing technology were developed.

The KALG contains liaison rules and constraints. It automatically generates all feasible sub-assemblies by eliminating the unfeasible sub-assemblies from the theoretical sub-assemblies. In the past this was performed manually which was a time consuming process prone to error.

The KPN is a technique for selecting the optimal assembly sequencing in terms of least assembly time by using a flow control mechanism. It ranks all feasible assembly routes and allows the engineer to select the preferred route as other considerations such as working area required etc. may be important. Where many routes have a similar ranking these other factors will need consideration. Prior to the development of this system the assembly times were generated manually and

not all routes were calculated. This could lead to the selection of non-optimal routes.

The four expert systems are decision trees using past experience as a rule base for easy selection of assembly system, feeder, gripper and sensing technology.

CIDAP documents the experience gained within the Company in the design of torches so that new engineers can follow the systems in designing new products without relying on the guidance of the experienced engineers. The framework together with the developed techniques and expert systems can be applied to any small and medium size companies in Hong Kong and China. They can modify the data file based on their own experience to suit their own use.

7. Conclusion

7.1 Application of CIDAP within the Company

There are many commercial software and systems available in the market. They are designed individually and are not integrated. Moreover, they are aimed for general use and hence cover a broad spectrum of industry. The rule base is too general for a company which produces a quite homogeneous product. In this Project, the Company developed the CIDAP framework and

its own expert systems and software based on its past years' experience and knowledge. It contains a number of knowledge-based systems which are not only applicable to the Company but also to similar light industry in Hong Kong. The developed CIDAP framework and software have the following advantages:

- It is an integrated system;
- It is more compact in size and relates to the type of product of the Company and similar industries in Hong Kong;
- The data file is compatible with those data normally used by the Company;
- It is easily understood by the designers and engineers of the Company, and hence provides a quicker reference.

The application results show that the proposed CIDAP framework is feasible, practical and easy to be used . It can be applied not only in the development of new products namely the H-series of torches, but also in the modification of existing products, namely the switch PBS-series.

The results obtained in going through the exercise were very encouraging. The objectives of the project as set out right from the start of the Project were accomplished. Total product development cycle time was reduced by 25% to six months. The amount of rework was significantly reduced while the product development cost was reduced by around 20%. It was observed that the working morale of the people involved was also greatly improved.

However, it should be pointed out that the Project is only an initial study of concurrent integrated design and assembly planning. It is desirable that much more research work should be continued to refine the methodology and the expert system development so as to establish a more integrated and intelligent environment of concurrent design of product and assembly processes. The data for the expert systems need periodic update as the Company collects more experience and expertise. The software used in the project was written by a technician who unfortunately left the Company and emigrated to Singapore. Hence, it is necessary for the Company to have someone to take up the job to debug it and to upgrade it periodically.

In order to run the new approach within the Company it is necessary to disseminate the knowledge to the product development department and to cultivate the concurrent and integrated philosophy to the entire organisation. The Research Engineer strongly believes that the CIDAP approach will gain wider acceptance within the organisation and will be practised for future product development.

7.2 Application of CIDAP outside the Company

Concurrent and integrated approach is widely accepted and practised in all business environments. The Project discussed and proposed a practical approach to product development. Though the original intention was to develop a system and tools for the Company, the Research Engineer

strongly believes that the same framework and tools including the techniques, the expert systems and the software packages are applicable to other small and medium size companies in Hong Kong and China with a similar scale and nature of operation. The Research Engineer also believes that the general data chart developed in this Project is also helpful to them. They can modify the data file based on their own experience to suit their own use.

7.3 Future work

The project is by no means at an end. It covers very broadly the areas of product design, design for assembly, assembly system design, assembly process planning, and flexible assembly planning and simulation. Each area can be a project in itself. The work covered in this Project is to consider integrating these areas concurrently to reduce total product development cycle time and to cut cost. Further work should be carried out in each area to improve the system. The Company sends every year some of its engineers to read the IGDS (Integrated Graduate Development Scheme) of the University of Warwick. One of them is doing a project for his final year MSc thesis under the Research Engineer's supervision. His project is on "Project Management: System Approach for Product Development". It will look into (i) the development of check lists for product part design and (ii) the team approach to identify potential design weaknesses before cutting metal for tooling. He will apply the approach developed in the Project to his work.

Other staff members studying IGDS will further the work of this Project to improve the expert systems and the data for the systems.

The KPN (Knowledge-based Petri Net) is a new and interesting approach. It warrants further work to improve the software to make it more user friendly as the original one was written for engineers' use. The Company is training one technician to rewrite the software using Windows so that it can be used by most people.

In order to further substantiate the applicability of CIDAP to the Company in product development, the Company will apply it to the development of the other two versions of the torch H-series, namely H230 and H550. The two models will be introduced in early 1997, and work was started in September 1996. The CIDAP approach will be used throughout the development cycle.

8. References

- [1] J.L. Nevis, D.E. Whitney, et al, "Concurrent Design of Products and Processes, A Strategy for the Next Generation in Manufacturing", McGraw-Hill Publishing Company, 1989
- [2] G. Boothroyd, P. Dewhurst, "Product Design for Assembly", Boothroyd Dewhurst, Inc., 1989

- [3] Boothroyd, Dewhurst and Knight, "Product Design for Manufacture and Assembly", 1994

- [4] H. J. Bullinger and M Richter, "Integrated Design and Assembly Planning", Computer Integrated Manufacturing Systems, Vol. 4, No. 4, pp.239-247, 1991

- [5] L.S. Homen de Mello and A.C. Sanderson, "Representation of Mechanical Assembly Sequences", IEEE Transaction on Robotics and Automation, 7(2), 211-227, 1991

- [6] H.K. Rampersad, "A Case Study in the Design of Flexible Assembly System", International Journal of Flexible Manufacturing Systems, Vol. 7, No. 3, pp255-286, 1995

- [7] A. Delchambre, "Computer-aided Assembly Planning", Published by Chapman & Hall, 1992

- [8] W. Zhang, "Representation of Assembly and Automatic Robot Planning by Petri Net", IEEE Transactions on System, Man, Cybernetics, 29(2), 418-422, 1989

- [9] G. Boothroyd, P.Dewhurst, "Product Design for Manufacture and Assembly",
Manufacturing Engineering, April 1988

[10] Lourdes M. Rosario, "Automatic Geometric Part Features Calculation for Design for Assembly Analysis", UMI, 1988

9. Bibliography

P. Alanche et al, "PSI: A Petri Net Based Simulator for Flexible Manufacturing Systems", Advances in Petri Net 1984, Lecture Notes in Computer Science 188, G. Rozenberg, Ed. NY: Springer-Verlag, pp.1-14, 1984

E. Arai and K. Iwata, "Product Modelling System in Conceptual Design of Mechanical Products", Robotics & Computer-Integrated Manufacturing, Vol.9, No.4/5, 327-334, 1992

A.J. Allen, K.G. Swift and G. Hird, "A Process Selection and Component Costing System in Support of Product Design", Design for Manufacture, Proceeding. IMechE, 1991

M. Andreasen and T. Ahm, "Flexible Assembly Systems", IFS Publications, UK, 1988

- A. Arpino and R. Groppeti, "ASSYST: A Consultation System for the Integration of Product and Assembly System Design", Development in Assembly Automation, IFS Ltd., March 1988
- D. F. Baldwin, et al, "An Integrated Computer Aid for Generation and Evaluation Assembly Sequences for Mechanical Products", IEEE Trans. on Robotics and Automation, 7(1), 78-94, 1991
- D. Ben-Arieh, "A Methodology for Analysis of Assembly Operation's Difficulty", International Journal of Production Research, 32(8), 1879-1895, 1994
- N. Boubekri and S. Nagaraj, "An Integrated Approach for the Selection and Design of Assembly Systems", Integrated Manufacturing Systems, Vol.4, No.1, pp.11-17, 1993
- H. Bullinger and U. Seidel, "Assembly Sequence Planning Using Operation Networks", Proceedings of 10th ICPR, Nottingham, 1989
- C.K. Choi et al " A New Approach to Automatic Assembly Sequence Generation", submitted to International Journal of Production Research, 1995
- J. Corbett et. al, "Design for Manufacturing, Strategy, Principles and Techniques", Addison-Wesley Publishing Company, 1991

- T. Csakvary, " Product Selection Procedure for Programmable Assembly Technique", Proceedings of 2nd International Symposium on Assembly Automation, Stuttgart, pp.353-62, 1982
- G. Dini and M. Santochi, "Automated Sequencing and Subassembly Detection in Assembly Planning", Annals of the CIRP, 41(1), pp.1-4, 1992
- T.L. DE Fazio and D.E. Whitney, " Simplified Generation of All Mechanical Assembly", IEEE Journal of Robotics and Automation, Vol.RA-3, No.6, 1987
- De Florianini and G. Nagy, "A Graph Model for Face-to-Face Assembly", Proceedings of the IEEE International Conference on Robotics and Automation, 1, pp.75-78,1989
- S. Grewal, et al, "Planning for Assembly", Proceedings of 11th International Conference on Assembly Automation, Dearborn, 1990
- Hird, et al, "Possibilities for Integrated Design and Assembly Planning", Proceedings of 9th International Conference on Assembly Automation, London, UK, March, Pugh. A. (ed.), Developments in Assembly Automation, Springer Verlag, IFS Publications, Bedford, UK, pp.155-166, 1988

W. Hsu, et. al, "Feedback Evaluation of Assembly Plans", Proceedings of the 1992 IEEE International Conference on Robotics and Automation, Nice, France, May, pp.2419-2424, 1992

S. Lee, "Disassembly Planning Based on Subassembly Extraction" . Proceedings of the 3rd ORSA/TIMS Conference on Flexible Manufacturing Systems. pp.383-388, 1989

K. H. Lee and J. Favrel, "Hierarchical Reduction Method for Analysis and Decomposition of Petri Nets", IEEE Trans. Syst. Man. Cybern., Vol.15, No.2, pp.272-280, 1985

S. Lee, and Y. G. Shin, "Automatic Construction of Assembly Partial Order Graphs", International Conference on Computer Integrated Manufacturing, Rensselaer Polytechnic Institute, May 23-25, pp.383-392, U.S.A, 1988

A. C. Lin and T. C. Chang, "An Integrated Approach to Automated Assembly Planning for Three Dimensional Mechanical Products", Int. J. of Pro. Res., 31(5), pp.1201-1226, 1993

E. Molloy et. al, "Design for Assembly with Concurrent Engineering", Annals of CIRP, 40(1), pp.107-110, 1992

- T. Murayama and F. Oba, "Concurrent Engineering Approach for Assembly Planning in Computer- aided Design: A Method for Generating Assembly/Disassembly Sequence", Proceedings of Pacific Conference on Manufacturing, Japan, pp.107-113, 1992
- T.L. Ng, "Project report on Performance variation and job enrichment on manual assembly work", MSc thesis in Industrial Engineering in the University of Hong Kong, 1978
- TL Ng et. al, "Knowledge-based Method for the Product Assembly Sequence Generation", Proceedings of the 7th International Manufacturing Conference in China (IMCC'95), Oct., 1995.
- J.L. Peterson, "Petri Net, Theory and the Modelling of Systems", Englewood Cliffs, NJ: Prentice-Hall, 1981
- H.K. Rampersad, "An Integrated Assembly Model", 1994
- A. Redford and J. Chal, "Design for Assembly Principles and Practice", 1994
- A. Redford, and E. Lo, "Robots in Assembly", Open University Press Robotics Series, in Davey, P.G.(Ed.), Open University Press, Milton Keynes, 1986

K.G. Swift et. al, "Design for Manufacture: An Opportunity for Expert System ",
3rd International Conference on Product Design for Manufacture & Assembly,
Newport, Rhode Island, 1988

N. Viswanadham and Y. Narahari, "Coloured Petri Net Models for Automated
Manufacturing Systems", Proceeding of the 1987 IEEE Int. Conference on
Robotics and Automation, Raleigh, N.C., pp.85-90, 1987

X. F. Zha et. al, "Intelligent Quality Control for Robotized Flexible Assembly
System", Proceedings of 1st Int. Conference on Quality and Reliability, April,
1995, Hong Kong, Vol.1, pp.324-332.